BELLCOMM, INC.
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B70 04055

SUBJECT: Space - vs - Ground Tradeoffs for Checkout Functions in a Space Station; an Ambiguous Situation
Case 105-6

DATE: April 10, 1970

FROM: J. R. Birkemeier

ABSTRACT

On manned missions conducted so far, inflight checkout functions have been handled on the ground. However, deep-space manned missions will require onboard checkout capability. Such a capability could be developed on a space station and would offer a number of operational advantages even for the space station: continuous monitoring of onboard systems, less dependence on communication systems, faster response, and less overall data handling.

Because of difficulties in obtaining, resolving, and projecting the proper data, a firm judgment between onboard and ground-based checkout cannot result from cost comparison only. However, it appears that onboard checkout could be done for as little as 21-48% of the cost of the ground-based method now used. The greatest cost factors involved in ground-based checkout are the annual operating costs of the Manned Space Flight Network (MSFN) and the Mission Control Center (MCC) at Houston. For a two-year mission, the costs of these facilities may total \$190-430 million, depending on the level of support required, the means used to relay data, and the portion of the total cost that is actually prorated for checkout. The largest part of the cost of onboard checkout comes from the ground support needed during the early phase of the mission, during resupply missions, and for a backup to the onboard equipment. For a two-year mission, this ground support comprises \$84 million total cost. Even if ground-based checkout were used throughout the mission, the cost of adding onboard checkout as an experiment would increase the total checkout cost only slightly.

Because of its operational advantages and lower cost, onboard checkout should be favored over ground-based checkout. However, a policy decision within NASA may be required to realize these benefits. Such a decision would demand assurances that space station systems are as reliable as expected and can be satisfactorily diagnosed by onboard facilities, and that flight controllers have enough confidence in the onboard equipment to relinquish much of the on-line support that has characterized manned space programs so far.

(NASA-CR-110629) SPACE VERSES GROUND TRADEOFFS FOR CHECKOUT FUNCTIONS IN A SPACE STATION, AN AMBIGUOUS SITUATION (Bellcomm, Inc.) 42 p

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MEMORANDUM FOR FILE

1.0 INTRODUCTION

A previous study (1) showed that an extensive amount of inflight checkout could be performed with the computer on board a mid-70's space station. Questions relating to the amount of checkout that should be performed on board were deferred. The present report analyzes this aspect of checkout in more detail. Although checkout functions are the primary concern here, the results of this study could be applied to other data management tasks as well.

1.1 Mission Assumptions

The space station considered here will have an operational lifetime of 2-5 years in Earth orbit. At scheduled intervals, typically 2-4 months (although shuttle vehicles could visit more frequently), resupply vehicles will be launched to visit the station. These vehicles will carry a supply of expendable stores for the station, relief for at least part of the crew, and systems, experiments, or modules to add to the station or to exchange for corresponding units already on the station.

The station may be launched as an integral structure with all systems installed, or may be assembled in orbit from two or more separately launched modules. The integral structure has the advantage of requiring a single launch, but is limited in weight to the payload capability of the launch vehicle. Therefore, in spite of the more complicated launch schedule and the need for rendezvous and docking procedures, a large station is likely to be modular and to require multiple launches.

Furthermore, the station may be launched either manned or unmanned. A manned launch necessitates a crew module which could be safely separated in case of abort. Moreover, an escape vehicle for the crew in orbit would need to be provided as part of the launch payload. Because of these complications, an unmanned launch of the space station, with the crew following closely in a separate launch, seems likely.

The amount of data to be handled could change considerably during the lifetime of the space station. The station itself will probably be of a new design, with no previous flight test. Many systems on board the station will also be new, with little or no flight test. Furthermore, the station will carry many new experiments and its crew will likely use a number of untried techniques and procedures in the course of the mission. Consequently, during the early phases of the mission, the onboard systems and the crew activities would receive intensive monitoring, comparable to that experienced on Gemini and Apollo flights. Later, as mission controllers become satisfied that the onboard systems were operating properly and that the crew procedures were adequate, the monitoring requirements might be relaxed.

Scheduled events during the mission would also affect the checkout requirements. Specific experiments will be turned on and off at various times. New modules brought up on resupply missions would need to be checked out thoroughly, off-line if possible, before being committed to service. The entry module that returns crew members to Earth would also require checkout before being used. All these factors could contribute to variations in data handling requirements.

It is important to distinguish between using the data produced by a system and monitoring the operation of that system. Different data requirements could apply. A guidance, control, and navigation system, for example, may update its solutions of attitude, velocity, and position equations several times a second during powered phases of flight. However, routine monitoring may be restricted to more slowly varying parameters like average power, temperatures, and pressures; more frequent or more extensive sampling would be done only if required for diagnostic testing. Consequently, data rates could change according to the health of onboard systems.

1.2 Summary of Checkout Functions

The primary purpose of inflight checkout is the safety of the crew and the successful completion of the mission. An important secondary purpose is the gathering of system performance data for mission planning purposes and for design evaluation and improvement.

Jennings(2) points out that system failures should be relatively infrequent on the space station: he derives an MTBF of seven days for the entire station. Therefore, the most common checkout function will be the monitoring of normally operating systems, a task well suited to automated methods. Monitoring would involve sampling system parameters at various rates, testing the parameters against preset limits, and alerting the crew when an out-of-tolerance situation develops. Trend analysis, using recent values of a parameter to predict near-future conditions, would be a profitable adjunct to monitoring.

When a parameter was found to be going out of tolerance, diagnostic testing would be conducted to isolate the source of the problem. Passive tests involving a more detailed analysis of available data would be used at first; if these failed to locate the trouble, active tests would be conducted. The latter would involve turning portions of systems on or off, selecting alternative modes, applying stimuli, or otherwise modifying the operation of a system, and comparing the actual response to the "ideal." Most of these tasks, if not all of them, could be handled by automatic equipment.

The crew would also have a role in inflight checkout, with such tasks as performing periodic inspections, generally supervising and directing the automated functions, and responding to unforeseen or peculiar occurrences. Crew members would also be expected to maintain and repair systems as far as practical.

2.0 GENERAL TRADEOFF CHARACTERISTICS

Data pertaining to the operation of the space station and its systems will necessarily originate on board the station. Similarly the end steps of active diagnosis must be executed on board, whether by a crew member or by a more or less automated checkout system. The tradeoff question centers on what to do with the data that is gathered and how to direct diagnostic testing.

In comparing various options for dividing checkout functions between spaceborne and ground-based facilities, three broad areas of expenditures arise:

1. cost - money spent to purchase, install, and operate equipment, and to maintain staffs;

2. payload capability - the weight, volume, power consumption, and special environmental requirements of onboard equipment;

3. time - constraints imposed by development, test, and delivery schedules.

Tradeoff studies seek to minimize the expenditure of resources in these areas without compromising the attainment of checkout objectives.

3.0 COMPARISON OF GROUND-BASED VS. SPACEBORNE CHECKOUT

3.1 Operational Comparisons

3.1.1 Ground-Based Checkout

So far, the manned space flight program has relied on the ground-based facilities and personnel to process and analyze spacecraft data. Samples of system parameters are sent directly to remote sites or, if no site is in contact, are recorded for later transmission. The Manned Space Flight Network (MSFN) relays the data to the Mission Control Center (MCC) at Houston for monitoring and for display to flight controllers. Commands from MCC are relayed to the appropriate site for transmission to the spacecraft.

Several advantages can be cited for ground-based checkout:

1. Greater resources are available on the ground:

large computer facilities, extensive and sophisticated software, and vast data storage capabilities.

2. A large number of technical specialists are on duty or on call to monitor the spacecraft systems and to assist in diagnosing and correcting malfunctions.

3. Redundancy for reliability can be more readily attained on the ground.

These advantages are not realized without some disadvantages. The experimental nature of the Gemini and Apollo programs, and the need to safeguard the crew at all times, has led to the development of a large, complex, and expensive organization in MCC.

Another disadvantage of the present system is the lack of continuous communication due to the spacing of the remote sites. Moreover, even when contact is established, time delays in the relaying of data greatly restrict the capability of the network to carry on a two-way data exchange. Telemetry data received at a site is read into a computer, where it is checked for format and selectively blocked for further transmission. Similar processing takes place at later points along the way to MCC. As a result, time delays of about 3-4 seconds are typical in relaying data from a remote site to MCC.

Although a command for the spacecraft computer can be relayed to a remote site in about five seconds, much longer delays, typically a minute or more, may occur in having the command verified and accepted on board. To safeguard against transmission errors, the commands are coded with a great deal of redundancy, which multiplies the number of bits transmitted and the amount of processing required to extract the desired information. Because of these factors in the present system, rapid dialogue between the space station and the ground, as would be required for the closely-timed, active diagnosis of the malfunction in a spaceborne system, may be limited to those short and infrequent periods when the station is in direct contact with MCC or with a suitable alternative. At other times, the control of active diagnosis, as well as the performance of passive diagnosis in situations where fast response was essential, would necessarily be done by onboard facilities.

Instead of remote sites, synchronous satellites could be used to relay data between the space station and MCC. Such satellites could provide continuous contact with the station and could relay data more quickly (one-half to one second for two-way communications with no end-point delay). However, satellites would act as simple repeaters of whatever data they received, without performing any of the verifying, editing, selecting, and blocking now done at the remote sites. Consequently, the computers at GSFC or MCC may need to handle data arriving at greater rates.

3.1.2 Onboard Checkout

Several advantages for onboard checkout can be cited:

1. There is less dependence on communication facilities: continuous coverage and immediate response are available without relay satellites.

2. Many factors affecting network transmission rates can be eliminated or at least made less restricting. Such factors include bandwidth and power, data redundancy and error checking, acknowledgement delays, and propagation and processing delays.

3. The overall data handling requirements can be relaxed: fewer bits, fewer tapes, etc.

4. The size and capacity of the space station impose hard limits on the number of people that can become involved in checkout activities and necessitate economy measures.

5. The installation of onboard checkout equipment at an early stage of manufacturing could lead to improvements in data consistency through use of the same checkout equipment at the factory, at the assembly area, on the launch pad, and during the flight.

6. The onboard checkout equipment could be used for a considerable amount of preflight checkout and could simplify the special equipment needed at the launch site.

7. Greater reliance on onboard systems is a step in the direction of the autonomy that will be required for spacecraft on planetary missions.

Some disadvantages also accompany onboard checkout. The onboard computer facilities must be enlarged to store the checkout program and data, execute the program at the required speed, handle input-output activities, and process interrupt conditions. These factors tend to increase the peak demands on the computer system and eventually lead to more weight, volume, and power consumption for onboard systems including spares, and possibly less of these resources for experiments. Computer controlled checkout, particularly active diagnostic testing, could also result in more complex spacecraft systems to provide the necessary test interfaces, with a resultant penalty in reliability and increased need for maintenance and repair.

The use of onboard checkout equipment may introduce schedule problems more serious than those encountered with ground-based checkout. The checkout equipment must be installed early in the manufacture of the spacecraft, and must itself be made and checked out still earlier in the project. To prevent the checkout equipment from becoming a critical item, off-the-shelf hardware may be selected, even if it weighs more or has somewhat less performance margin than would be desired.

One of the major problems associated with automated checkout, whether on board or on the ground, is the technical feasibility of developing suitable diagnostic programs. The conditions that limit the amount of crew time that can be allocated to checkout functions also place more emphasis on automated methods on board than would be the case on the ground. Consequently, the diagnostic programs for onboard checkout may need to be more comprehensive and be able to deal with a broader range of contingencies. In a similar vein, the crew of the space station would need a better understanding of the systems, their operation and diagnosis, to be able to handle problems as they arise.

Many of the difficulties of onboard checkout could be alleviated by treating ground-based checkout as a backup, to be called on if special assistance were needed to isolate or repair a fault. However, delays may be experienced in marshalling the necessary personnel or facilities to tackle a particular trouble. Consequently, onboard systems should be designed for fail-safe operation as much as possible. Graceful degradation and backups, at least for critical systems, should also be considered.

3.2 Cost Comparisons

Accurate cost data is generally very elusive. Costs experienced to date in the manned space flight programs are often difficult to obtain and to resolve into desirable groupings. More complications arise when applicable cost figures must be projected to future systems. Under these conditions, the best that can be expected is an order-of-magnitude comparison, with firm conclusions drawn only if alternatives show differences of one or more orders of magnitude.

Most of the cost data presented below was obtained informally, and in many cases represents a considered judgment on the part of the author or the source of the data.

3.2.1 Cost of Using Existing Ground Facilities

The cost of supporting the space station with existing ground facilities can vary greatly with the number of other missions being supported concurrently.

MSFN equipment has a low duty cycle on a given mission: a typical site makes 6-8 contacts per day with a vehicle orbiting at 200-260 n. mi., and each contact lasts 8-10 minutes. Therefore, the transfer of data between the space station and a remote site would be characterized by short, concentrated bursts, followed by long periods without contact. Other, concurrent missions could be supported at the site during these periods.

A somewhat similar situation exists at MCC. Present facilities can fully support two concurrent missions of the complexity of Apollo in their real-time phases of training, checkout, and actual flight. In addition, computing facilities allow programs for other missions to be developed and tested simultaneously. This sharing of MCC resources among several missions, while an important factor in the

Gemini and Apollo programs, will be less of an asset for the space station, whose resupply vehicles may show far less need for support than has been the case with other manned vehicles so far.

Another factor to be considered in checkout cost analysis is the use of remote sites for functions other than handling performance data: tracking data is also gathered and relayed. For a short-duration flight, or one involving a maneuvering spacecraft, tracking is a key task in mission control. However, a space station would normally remain in the same orbit for a long period of time; after the orbital parameters were established early in the flight, tracking would diminish in importance. Therefore, the prorated cost of operating a remote site could be charged to data handling needs of the space station, rather than being divided between data handling and vehicle tracking.

With these qualifications in mind, the costs of operating the ground facilities can be examined. The annual cost for the remote sites and supporting facilities at GSFC is about $115 million. This cost includes 100-150 personnel who prepare the programs for the telemetry and command computers used at the remote sites for Apollo missions.

The large amounts of raw data sent to MCC require extensive programs there for processing and analysis. Manpower and computer costs now total $50-100 million per year.

If the present methods of conducting a manned mission were applied to the space station, the gathering and processing of system performance data and the issuance of commands to the station could be expected to cost $165-215 million per year. This range may be regarded as bounds on an upper limit, to be applied if the space station were the only mission at that time, and if the full resources of the MSFN and the MCC were available to it.

Several factors, however, would tend to reduce these cost figures substantially:

1. The second control room at MCC could support another mission of the same type concurrently without any significant incremental cost. A third mission might also be supportable, if at least one mission required only a low level of support. The cost could then be distributed:

$80-110 million per year for each of two missions, or $55-70 million per year for each of three missions.

2. The support requirements for a long-term, operational vehicle like a space station and its resupply vehicles will probably be much less than those for the more experimental manned flights conducted so far. This factor alone could reduce the costs of operating MCC. However, the amount of reduction possible is difficult to estimate. A reasonable cut might be 50%.

3. Checkout-related functions like telemetry and command processing comprise only about one-third of the computer memory required for MCC. Other real-time tasks of comparable size are mission planning, orbit computations, and trajectory determination. If the costs of operating MCC ($50-100 million per year) were prorated by a similar factor, the checkout costs could be considered to be about $20-35 million per year.

4. Experiments conducted on the space station may require contact with MCC, at least during those periods when the experiments are being performed. The data rates needed for experiments are apt to be high, especially if image sensing is involved. Checkout data could then be added to the transmission. The prorated cost of handling checkout data would therefore be reduced.

3.2.2 Cost of Using Variations of Existing Ground Facilities

Several variations in present operating methods can be considered for purposes of cost reduction. Studies within NASA and by contractors are continually trying to streamline the current scheme of operation to make it more cost-effective. The following examples show some possibilities.

Data Relay Satellites

Synchronous satellites could replace the remote sites as a means of relaying data between the space station and MCC. A satellite system dedicated to this service would cost an average of $20-40 million annually over a ten-year period for development, installation, and operation. The gradual phasing out of part of MSFN could lead to a small net savings for the ten-year period.

An alternative approach would be to lease channels on communication satellites like Intelsat IV. This approach has the advantages of not requiring a long development program and being available much earlier than the dedicated satellite system. Use of Intelsat IV to replace some remote sites could reduce the total network cost to about $75 million annually. The loss of these sites would result in narrower launch windows. However, the Apollo program has dramatically demonstrated the ability of KSC to launch complicated vehicles on schedule. If such success continues, future missions may not need the wide launch windows that were allowed for Apollo.

Additional Processing at Remote Sites

The relaying of data from a remote site to MCC involves a comparatively low rate at present, 2.4 kbps per line. This rate is to be doubled in the near future. Although the computers at the sites do a considerable amount of manipulation of the data, the output rate sets the pace for the entire process. As a result, only one-quarter of the processing power (CPU time) of the computer is actually used. Some of the excess capability of the computer could be devoted to checkout functions. Additional memory may be needed, but this could be provided without significantly affecting the cost of operating the site.

Data compression is another function that could be added to the remote site computers. For space station systems operating normally, consecutive samples of parameters would show little variation. Data compression techniques could then be used to reduce the amount of data transmitted to MCC. Such techniques may become necessary if large amounts of data are to be sent from the space station. Furthermore, routine monitoring of space station systems could be incorporated into the remote site processing. Aside from relaxed data transmission requirements, this scheme has the advantage of reducing the delays inherent in present MSFN data handling while the space station is in contact with the remote site.

Combined Ground Facilities

Since many data handling functions are common to manned and unmanned flights, a combined network to support both kinds of flights can be considered. Some remote sites could then be shut down. However, each network tends to support different kinds of missions with different requirements, so that the exact manner of combining the two is not known at this time. The cost of operating the combined facilities could be as low as $200 million per year, to be shared between manned and unmanned missions. In case of conflicting demands on the network at any one time, the manned mission would normally have priority, especially if crew safety were involved. However, such conflicts should be rare and should cause only minor scheduling difficulties.

3.2.3 Cost of Onboard Processing

In Section 3.1.2, it was mentioned that program schedules may cause off-the-shelf equipment to be selected for onboard checkout tasks. Consequently, it is wise to base cost estimates on less than the most advanced computer technology that may be available during the fabrication phase of the space station.

Performing checkout functions on board the space station would require either a separate checkout computer or an expansion of the existing computer to handle the checkout program. According to Reference 1, memories approaching 131K words will be necessary for typical checkout tasks. Erasable memories of this size tend to be comparatively heavy and would result in a computer that would, on the average, weigh 300 lbs., occupy five cubic feet, and consume 1100 watts of power.

The large number of test points addressable by the checkout equipment would require an extensive input-output interface with the computer. With today's integrated circuit technology, the multiplexers, registers, and other modules may add another 100 lbs., occupy two cubic feet, and consume 100 watts of power.

The combined weight, volume, and power for the computer and its interface would then be 400 lbs., 7 cubic feet, and 1200 watts, respectively. (These figures ignore any savings in weight and power that may result from reducing the telemetry data transmission rate.) The power requirement may be translated to additional weight. Factors of one-half to one pound per watt are commonly used. The computer would then add 1000-1600 lbs. to the space station systems' weight. One way of expressing this weight as a cost factor is to distribute launch costs among the various systems by weight. A Saturn V can launch a pound of payload into Earth orbit for about $1000. The checkout computer would therefore cost $1-2 million to launch. This range of values is a liberal allowance for the space station.

The checkout computer itself would cost $0.25-0.5 million. The interface equipment and its integration into the system would cost a comparable amount. Furthermore, it would probably be necessary to procure at least one or two units in addition to the flight unit, to permit program testing and to provide a spare. Therefore, the cost of the computer hardware would be about $2 million.

Software cost is another problem area. Historically, the aerospace computers have been expensive to program, when compared to similar tasks performed on ground-based computers. This higher cost can be attributed to a number of factors:

1. Lack of floating-point hardware required more care to avoid scaling problems with fixed-point data formats.

2. Division of memories into a large fixed section and a small erasable section resulted in allocation problems.

3. Lack of large memories caused aerospace programs to crowd whatever memory was available, with considerable reprogramming necessary to make the whole program fit.

4. The relative scarcity of programming aids like higher-order languages, flexible executive routines, and debugging tools necessitated the use of more error-prone machine-language or assembly-language coding.

5. The lower tolerance of failure in an aerospace environment required the programs to have the highest reliability possible and necessitated extensive qualification testing.

6. Changing requirements led to the reworking of large segments of programs that were already wholly or partly checked out, and often aggravated problems that arose from the above sources.

All these factors should impose less of a penalty on aerospace computers in the near future. Erasable random-access memories are available within acceptable limits of weight, size, and power consumption. Floating point arithmetic is becoming more common. Programming aids are becoming more plentiful for aerospace computers, especially when compatibility between aerospace and ground-based computers allows at least some software to be shared between the two types. Furthermore, the availability of large memories and faster speeds will enable the aerospace computers to accommodate program requirements with less optimization and crowding. The need for safe, reliable programs operating without benefit of the multiple-computer backup technique possible on the ground will continue, but should be more easily met with these various improvements in aerospace hardware and software. Therefore, the cost of developing software for an aerospace computer should not differ greatly from the cost of preparing similar software for a ground-based computer.

Experience with the Acceptance Checkout Equipment (ACE) used for the preflight checkout of a manned spacecraft at KSC shows that about one manyear of programmer time is needed to develop the program for a major space vehicle like a command module or a lunar module. However, many more man-years of effort were required to develop the problem-oriented language and the executive system that allows these programs to function as intended. A similar expenditure would be needed for the spaceborne checkout computer, and would be comparable to the cost of the computer itself. For estimating purposes, it can be assumed that the software will cost at least as much as the hardware; a higher estimate for software allows a better margin in developing the special routines needed to address a large number of interface points. Therefore, the software cost is estimated at $3 million.

Historically, the programming of large aerospace computers has progressed at an average rate of 2.5-3.0 checked-out instructions per manday. At this rate, and at an assumed manpower cost of $100 per manday, a program that fills a 131K memory would cost $4.4-5.4 million. For the reasons cited above, however, higher programming rates should be possible in the future, and the $3 million estimate given above is acceptable.

3.2.4 Cost of Supplementary Ground-Based Processing

Even with extensive onboard processing, some data would be sent to the ground, if for no other reason than to provide an overall monitoring of the space station, including its checkout capabilities. "Snapshots" of parameter samples and descriptive statistical quantities would be typical data transmitted to MCC. When malfunctions occurred, increased sample rates might be desired for analysis on the ground. These increases could be accomplished by taking more frequent samples of system parameters, doing less compression, or both.

If no ground station was in contact, it would be necessary to record the data on board for later transmission to the ground. Alternatively, a satellite could relay the data to the ground. With a modest antenna size and power requirement for the space station, a communication satellite like intelsat IV could provide such a data link at a cost of about $6 million per year.

Once the data was received at MCC, flight controllers, technical specialists, and others could examine it. In the case of malfunctions, these personnel could assist in the diagnosis by directing the onboard facilities, either immediately or through the flight crew. Support personnel on the ground could also run tests and simulations during the mission to assist in diagnosis and repair or to derive new procedures for onboard checkout.

This supplementary processing differs from ground-based checkout in the timeliness of the data: with extensive onboard capability, ground support would not need to be done in real time. Because of the more leisurely response, MCC would need nowhere near the staff and facilities now used to support a mission. However, just how much would be needed is difficult to evaluate because of the number of contingencies: how reliable onboard systems really prove to be, how thorough the onboard diagnostic programs can be, how much confidence will be placed in onboard processing, and how many missions will be conducted concurrently. The lowest figure developed in 3.2.1, $20 million per year, could be a minimum cost for this support.

3.2.5 Cost Summary

Many of the cost figures given in the preceding sections are estimates subject to variation. To use these figures, additional assumptions must be made here. Consequently, the results developed here could change with different assumed values, although hopefully the major conclusions would not be seriously degraded.

The cost figures cited in the preceding sections can be combined in various ways to produce a range of estimates. Table 1 shows the results for ground-based checkout using two levels of MSFN capability and four kinds of MCC support. The totals cover a range of $95-215 million per year. If another mission were supported concurrently through the same facilities, these costs could be halved: $50-110 million per year. For a two-year mission, all these figures should be doubled to arrive at the total cost: \$190-430 million for a single mission, or \$100-220 million for each of two missions.

Costs for onboard checkout contain both one-time and recurring items. The once-only items include:

computer hardware	\$2 million
computer software	3 million
launch to Earth orbit	2 million
Total	\$7 million

In addition, heavy ground support would be given the space station during the early phase of the mission. How heavy this support is and how long it lasts are still highly questionable. For estimating purposes, it is assumed that the present full capability of MCC would be used for one month. (It is also assumed that, after this one-month period, the personnel and facilities in excess of continuing mission needs could be diverted to other tasks or otherwise removed from chargeability to the space station.) The prorated cost of this support would be 1/12 of \$100 million or \$8 million. A reduced MSFN with Intelsat IV could also be used, at a prorated cost of 1/12 of \$75 million, or \$6 million. The one-time costs would then total \$21 million.

Two kinds of recurring cost can be associated with onboard checkout: supplementary ground support and resupply mission support. Supplementary ground support could be provided continuously at a cost of \$6 million per year for Intelsat IV and \$20 million per year for MCC. Resupply missions could present a variety of support requirements. Space shuttles on routine missions may be highly self-sufficient; other kinds of vehicles may require more intense support for a few days. For estimating purposes, it is assumed that:

1. Four resupply missions occur each year;

2. Each mission requires intense support for four days;

3. The level of support is comparable to that given the space station during its early phase (\$215M/365 = \$0.59M per day).

The cost of this support would then be about \$9 million per year. Therefore, the total recurring cost would be \$35 million per year. For a two-year mission the combined costs would then be $91 million. This figure is 48-21% of the $190-430 million cost of ground-based checkout. However, the assumptions made regarding supplementary ground support for onboard checkout are open to argument, and the overall cost of onboard checkout could easily be twice the value given above. Therefore, it can be stated with some confidence only that onboard checkout will cost no more than ground-based checkout, and will probably cost less.

4.0 CONCLUSIONS

In areas other than cost, onboard checkout has a number of advantages: continuous coverage with less dependence on communication facilities, less overall data handling, and early integration of checkout equipment with the space station. These advantages are obtained at the price of more complex onboard systems, more weight, and possible interference in hardware and software development schedules. However, it may also be argued that onboard checkout should be implemented on the space station as a step toward developing the capability that will be needed on later, deep-space missions.

Onboard checkout by itself could cost far less than ground-based checkout. However, the need for data links and some ground support, at least as a backup, increases the cost of onboard checkout to a level approaching that of a reduced version of the present ground support complex. But onboard checkout would still be cheaper than the ground-based system used now. Therefore, onboard checkout is favored over ground-based checkout, but the cost difference is not great enough to allow a firm judgment to be made at this time.

Since the cost of onboard checkout by itself is comparatively low, it should be used whether or not ground-based processing is retained as the primary means of inflight checkout. Onboard checkout could even be treated as an experiment, and would increase the total checkout cost only slightly.

The present study has been concerned mostly with technical and economic comparisons. The implementation of onboard checkout may well end up as a policy decision within NASA. In arriving at such a decision, the question of confidence in onboard systems is certain to arise. With the manned missions that have been conducted so far, lack of continuous contact, time delays, and communication rate limitations have restricted the degree to which the ground support complex could respond to problems on the mission. As a result, the crew and their onboard systems have of necessity been trusted to perform satisfactorily. A somewhat similar situation exists on the Apollo lunar missions: the firing of the service propulsion system to place the spacecraft into or out of lunar orbit occurs on the far side of the moon, when the spacecraft is completely out of contact with MCC. If the spacecraft were destroyed by a catastrophic engine failure, no one would know why. However, no feasible alternative exists, and so the missions are conducted with this handicap. Economic or other restraints may force similar policy decisions to be made with regard to the space station and may result in great reliance being placed in onboard checkout.

JRBirkemeier

1031-JRB-rghe J. R. Birkemeier

Attachments
References
Table 1

References

1. "Onboard Checkout of a Mid-70's Space Station - Case 730," Bellcomm Technical Memorandum TM-69-1031-3, J. R. Birkemeier, June 6, 1969.

2. "Reliability and Maintainability Analysis of a Two Year Manned Spacecraft Mission," Hugh A. Jennings, The Boeing Company, (presented at AIAA 5th Annual Meeting and Technical Display, October 21-24, 1968).

TYPE OF MSFN →	PRESENT MSFN CAPABILITY	REDUCED MSFN WITH INTELSAT IV
COST →	115	75

↓ TYPE OF MCC SUPPORT	↓ COST
PRESENT LEVEL	100
REDUCED LEVEL	50
PRESENT LEVEL, CHECKOUT SUPPORT ONLY	35
REDUCED LEVEL, CHECKOUT SUPPORT ONLY	20

215	175
165	125
150	110
135	95

COMBINED COSTS

ALL COSTS IN MILLIONS OF DOLLARS PER YEAR

TABLE 1

COSTS OF GROUND-BASED CHECKOUT ALTERNATIVES

BELLCOMM, INC.

Subject: Space - vs - Ground Tradeoffs for Checkout Functions in a Space Station; an Ambiguous Situation - Case 105-6

From: J. R. Birkemeier

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